Searches for the Higgs boson at the Tevatron

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Abstract. We present the results from the Tevatron on the direct searches for Standard Model Higgs boson produced in $p\bar{p}$ collisions at a center of mass energy of 1.96 TeV, using the data corresponding to the integrated luminosity of 10fb^{-1}. The searches are performed in the Higgs boson mass range from 100 to 200 GeV/c^2. The dominant production channels, $H \to b\bar{b}$ and $H \to WW$, are combined with all the secondary channels and significant analysis improvements have been implemented to maximize the search sensitivity. We observe a significant excess of data events compared to background predictions with the local significance of 3.0 standard deviations. The global significance for such an excess anywhere in the full mass range investigated is approximately 2.5 standard deviations.

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INTRODUCTION

The Higgs boson is a crucial element of the standard model (SM) of elementary particles and interactions. Within the SM, vector boson masses arise from the spontaneous breaking of electroweak symmetry due to the existence of the Higgs particle. The winter results from the LHC and the Tevatron experiments have excluded wide regions of the possible Higgs mass ranges. The most interesting region to search for the Higgs is the mass range between 115 and 127 GeV/c^2 where the both the ATLAS and the CMS experiments have found some excesses [1, 2]. The Tevatron experiments can contribute to the understanding of this region by analyzing the data collected through the years of 2001-2011.

HIGGS SEARCH CHANNELS AT THE TEVATRON

Low Mass Channels

The SM Higgs boson H is predicted to be produced in association with a W or Z boson at the Fermilab Tevatron $p\bar{p}$ collider and its dominant decay mode is predicted to be into a bottom-antibottom quark pair ($b\bar{b}$), if its mass m_H is less than 135 GeV/c^2 (low Higgs mass region). The searches use the complete Tevatron data sample of $p\bar{p}$ collisions at a center of mass energy of 1.96 TeV collected by the CDF and D0 detectors at the Fermilab Tevatron, with an integrated luminosity of 9.45 fb^{-1} – 9.7 fb^{-1}. The CDF and D0 detectors are multipurpose solenoidal spectrometers surrounded by hermetic calorimeters and muon detectors and are designed to study the products of 1.96 TeV proton-antiproton collisions [3, 4].

The online event selections (triggers) rely on fast reconstruction of combinations of high-p_T lepton candidates, jets, and $\not{E}_T$. Event selections are similar in the CDF and D0 analyses, consisting typically of a preselection based on event topology and kinematics, and a subsequent selection using b-tagging. Each channel is divided into exclusive sub-channels according to various lepton, jet multiplicity, and b-tagging characterization criteria aimed at grouping events with similar signal-to-background ratio and so optimize the overall sensitivity.

Due to the importance of b-tagging, both collaborations have developed multivariate approaches to maximize the performance of the b-tagging algorithms. A boosted decision tree algorithm is used in the D0 analysis, which builds and improves upon the previous neural network b-tagger [5], giving an identification efficiency of $\approx 80\%$ for b jets with a mis-identification rate of $\approx 10\%$. The CDF b-tagging algorithm has been recently augmented with an MVA [6], providing a b-tagging efficiency of $\approx 70\%$ and a mis-identification rate of $\approx 5\%$.

In $H \to b\bar{b}$ final states, the single most sensitive observable to distinguish between the Higgs signal and various types of background is the invariant mass of dijet system, m_{jj}, which approximately accounts for 75% of analysis sensitivity. In all low mass Higgs searches at Tevatron, we include additional variables through the multivariate analysis techniques. Dedicated studies have been performed to improve the search sensitivity through the improvements in dijet mass resolution, lepton identification algorithm, b-tagging, multijet background suppression and modeling, final discriminant optimization. The detailed information on low mass Higgs channels is present in Ref. [7, 8, 9, 10, 11, 12]

To validate our background modeling and search methods, we perform a search for SM diboson production in the same final states used for the SM $H \to b\bar{b}$ searches. The data sample, reconstruction, process modeling, uncertainties, and sub-channel divisions are identical to those of the SM Higgs boson search. The measured cross section for WZ and ZZ production is $\sigma(WW+WZ) = 4.47 \pm 0.64$ (stat) $^{+0.73}_{-0.72}$ (syst) pb [13]. This is consistent with SM prediction of $\sigma(WW+WZ) = 4.4 \pm 0.3$ pb [14] and corresponds to a significance of 4.6 standard deviations above the background-only hypothesis.

Other Complimentary Channels

Even though $H \to b\bar{b}$ final states are the most sensitive channels at the Tevatron below 135 GeV/c^2, in the final combination we consider all the complimentary channels to improve the Higgs search sensitivity. The complete list of channels that goes into the Higgs Tevatron combination is given in Ref. [15]. One of the channels that needs to be mentioned is $H \to WW$. Being the most sensitive channel for the high mass Higgs region, it has significant contribution to the low mass region as well. For the $H \to WW$ analyses, signal events are characterized by large $\not{E}_T$ and two opposite-signed, isolated leptons. The presence of neutrinos in the final state prevents the accurate reconstruction of the candidate Higgs boson mass. The most sensitive variable for Higgs signal is the opening angle, ΔR, between the outgoing leptons. Both CDF and D0 include additional event properties and their correlations through multi variate algorithms. CDF

uses neural network outputs, including likelihoods constructed from calculated matrix element probabilities and D0 uses boosted decision trees outputs.

TEVATRON COMBINATION

In the Tevatron combination, we combine all the major low mass Higgs channels with the complimentary final state searches from CDF and D0. In this section we report the results presented at CIPANP conference, which are based on analyses presented for the Winter conferences and described in more detailes in Ref. [15].

To determine the estimates of the interest like the upper limits on SM Higgs production at 95% C.L. and to gain confidence that the final result does not depend on the details of the statistical formulation, we perform two types of combinations: Bayesian approach where the nuisance parameters are integrated out to determine posterior probabilities; and Modified Frequentist approach where the minimum of the likelihood is used to determine the nuisance parameters. Both approaches yield limits on the Higgs boson production rate that agree within 10% at each value of m_H, and within 1% on average. Systematic uncertainties enter on the predicted number of signal and background events as well as on the distribution of the discriminants in each analysis ("shape uncertainties").

The 95% C.L. limits on Higgs production are shown in Fig. 1, along with the significance of the excess in the data over the background prediction, assuming a signal is truly absent. The regions of Higgs boson masses excluded at the 95% C.L. are $100 < m_H < 106$ GeV/c^2 and $147 < m_H < 179$ GeV/c^2. The expected exclusion regions are $100 < m_H < 119$ GeV/c^2 and $141 < m_H < 184$ GeV/c^2. There is an excess of data events with respect to the background estimation in the mass range $115 < m_H < 135$ GeV/c^2. The observed p-value as a function of m_H exhibits a broad minimum, and the maximum local significance corresponds to 2.7 standard deviations at $m_H = 120$ GeV/c^2. Correcting for the Look-Elsewhere Effect (LEE), which accounts for the possibility of a background fluctuation affecting the local p-value anywhere in the search region, yields a global significance of 2.2 standard deviations.

UPDATED RESULTS

We have recently updated and combined the results in $H \to b\bar{b}$ final states at CDF and D0 [16]. An observation of this process would support the SM prediction that the mechanism for electroweak symmetry breaking, which gives mass to the weak vector bosons, is also the source of fermionic mass in the quark sector.

The broad observed excess in the low mass range, shown on Fig. 2, results in a minimum p-value of 3.3 standard deviations away from the background-only hypothesis at a Higgs mass of m_H = 135 GeV/c^2. The global p-value is 3.1 standard deviation. We interpret this result as evidence for the presence of a particle that is produced in association with a W or Z boson and decays to a bottom-antibottom quark pair. The excess seen in the data is most significant in the mass range between 120 and 135 GeV/c^2, and is consistent with production of the SM Higgs boson.

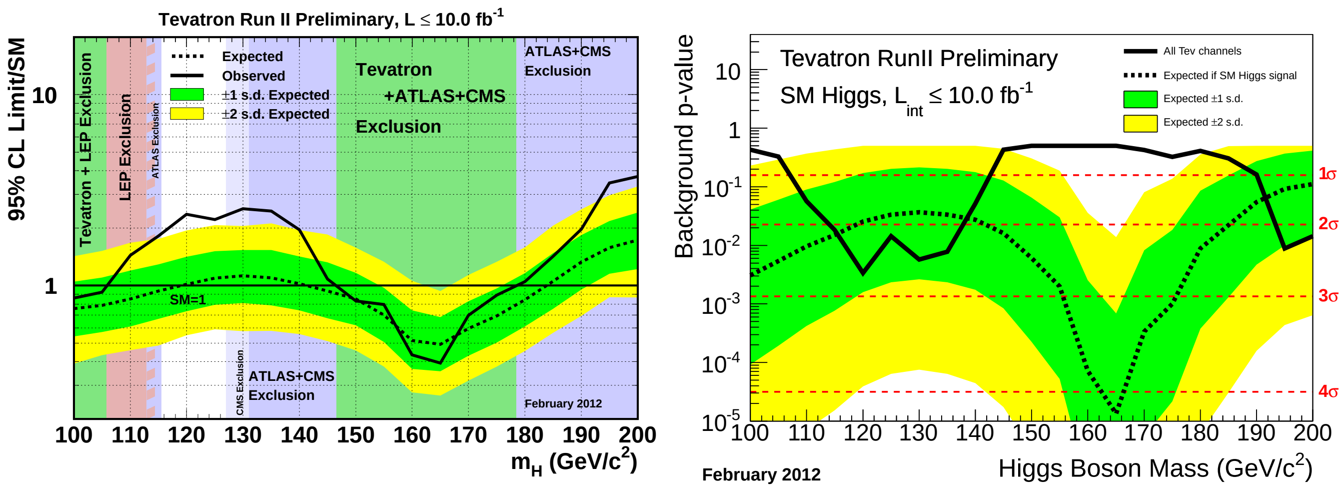

FIGURE 1. Final Tevatron combination for the winter conferences: (Left) The observed 95% credibility level upper limits on SM Higgs boson production as a function of Higgs boson mass. The dashed line indicates the median expected value in the absence of a signals. (Right) The p-value as a function of m_H under the background-only hypothesis. The associated dark and light-shaded bands indicate the 1 s.d. and 2 s.d. fluctuations of possible experimental outcomes.

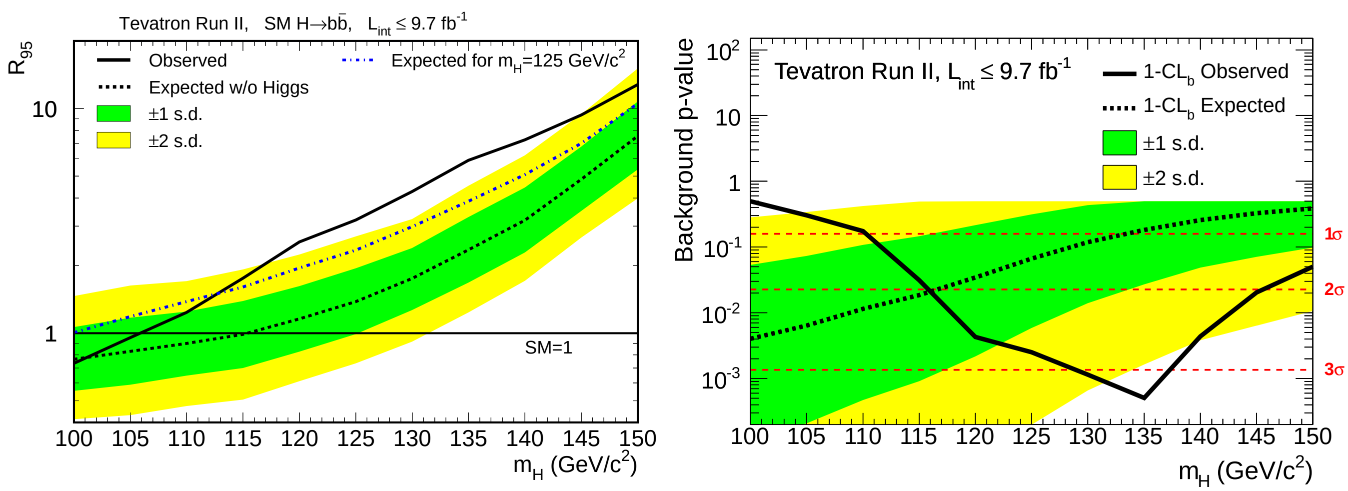

FIGURE 2. Updated Tevatron combination for $H \to b\bar{b}$ channels: (Left) The observed 95% credibility level upper limits on SM Higgs boson production as a function of Higgs boson mass. The dashed line indicates the median expected value in the absence of a signals. (Right) The p-value as a function of m_H under the background-only hypothesis. The associated dark and light-shaded bands indicate the 1 s.d. and 2 s.d. fluctuations of possible experimental outcomes.

The updated Tevatron combination [17] across all channels on CDF and D0 yields the local(global) significance for such an excess of 2.5(3.0) standard deviations.

CONCLUSIONS

We combine all available CDF and D0 results on SM Higgs boson searches. A broad excess is observed in data with respect to the background estimation, corresponding to a 2.5 standard deviations. Considering only the $H \to b\bar{b}$ final state searches yields an excess, corresponding to a 3.1 standard deviations. The excess is observed to be consistent with SM Higgs boson production.

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